SYNOPTIC ANALYSES OF THE UPPER STRATOSPHERIC CIRCULATION DURING THE LATE WINTER STORM PERIOD OF 1966

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ABSTRACT

Rocketsonde observations obtained by the Global Meteorological Rocket Network were utilized in the investigation of the stratospheric circulation of the western portion of the Northern Hemisphere during the period Feb. 1–15, 1966. Synoptic and vertical time section analyses presented evidence of the temporary breakdown of the winter westerlies. The analyses, performed for the first time at intervals of less than 1 week at the 1-mb. surface, show circulation systems which change completely in the strata between the middle and upper stratosphere. This is synoptically illustrated at 10 mb. by contraction of the hemispheric winter cyclone into polar latitudes and by splitting of this cyclone at 1 mb. and its subsequent weakening and displacement into midlatitudes. Warming in the upper stratosphere appears to be the major contributing cause for these circulation changes.

1. INTRODUCTION

This report summarizes an investigation of time and space variabilities of motion and temperature between the tropopause and stratopause during the late winter storm period of 1966. Evidences of a wind reversal and associated minor warming over the United States and Canada were clearly illustrated on synoptic charts and diagrams. Studies of circulation reversals (Keegan [1], Finger and Teweles [2], Morris and Miers [3], Labitzke [4]) have demonstrated the occurrence of significant synoptic changes in the stratospheric circulation.

Wind and temperature observations acquired by rocket probes in the stratosphere have substantially increased during the past year, enabling the synoptic meteorologist to analyze and interpret the stratospheric data with increased confidence. Most of the data utilized were obtained through the use of 90 rocket and 10 gun-launched projectile firings and related radiosonde soundings from the Meteorological Rocket Network (MRN) Data Report for February 1966. Three other rocket observations used were two Skua firings at West Geirinish, Scotland, on Feb. 8 and 10, 1966, and an Arcasonde at Fort Churchill on Feb. 14, 1966. Temperature and wind data were acquired from these firings. Fortunately, the largest number of firings (19) were made on Feb. 10, 1966, when the reversed circulation was evident.

Construction of the diagrams necessitated some subjectivity in the analyses, particularly since few observations covering so vast an area were available on any 1 day. Data were adjusted when they appeared to be in error. Interpolation and extrapolation techniques were used only when necessary to insure space and time continuity.

The measurements of temperature and wind obtained by radiosonde and rocketsonde sensors appeared to be compatible ($\pm 2°$C. and ± 3 m./sec.) at approximately 25 km. All data used in these analyses below 25 km. were acquired by radiosonde and above 25 km. by rocketsondes.

The following procedure was used in preparing the 1-mb. maps. Geopotential heights over each station were extracted from 10-mb. charts (National Meteorological Center, Weather Bureau, ESSA). The height of 1-mb. surface was initially approximated by using the value listed in the thermodynamic data in the MRN Data report and then determined by calculating the mean temperature between the height at 10 mb. and 48 km. employing observed readings at intervals of 2 km. The appropriate height was then taken from a table of values (computed hydrostatically) which listed height as a function of mean temperture and it was added to the height shown on the 10-mb. surface. If the 1-mb. height appeared to be in error after considering the thermal wind relationship which utilizes the winds at the 1-mb. surface and at 2-km. height increments above and below this surface and also space and time continuity in temperature and winds, then a second approximation was required wherein heights at the lower and upper boundaries were readjusted and a new mean temperature and height were calculated. Contour patterns that were changing rapidly occasionally required third and fourth boundary height approximations before a reasonable height at the 1-mb. surface was obtained. From these height values, contours were drawn for every 200-gp.m. with an appropriate geostrophic wind scale. A differential analysis (thickness lines) was also entered on the 1-mb. charts.

The accuracy of the 1-mb. surface contour analysis, as described above suffered from errors of several sources, i.e.:

1) The mean temperature between 10 mb. and 1 mb. will be in error by an amount equal to the mean error of temperature as a function of height. For each degree of

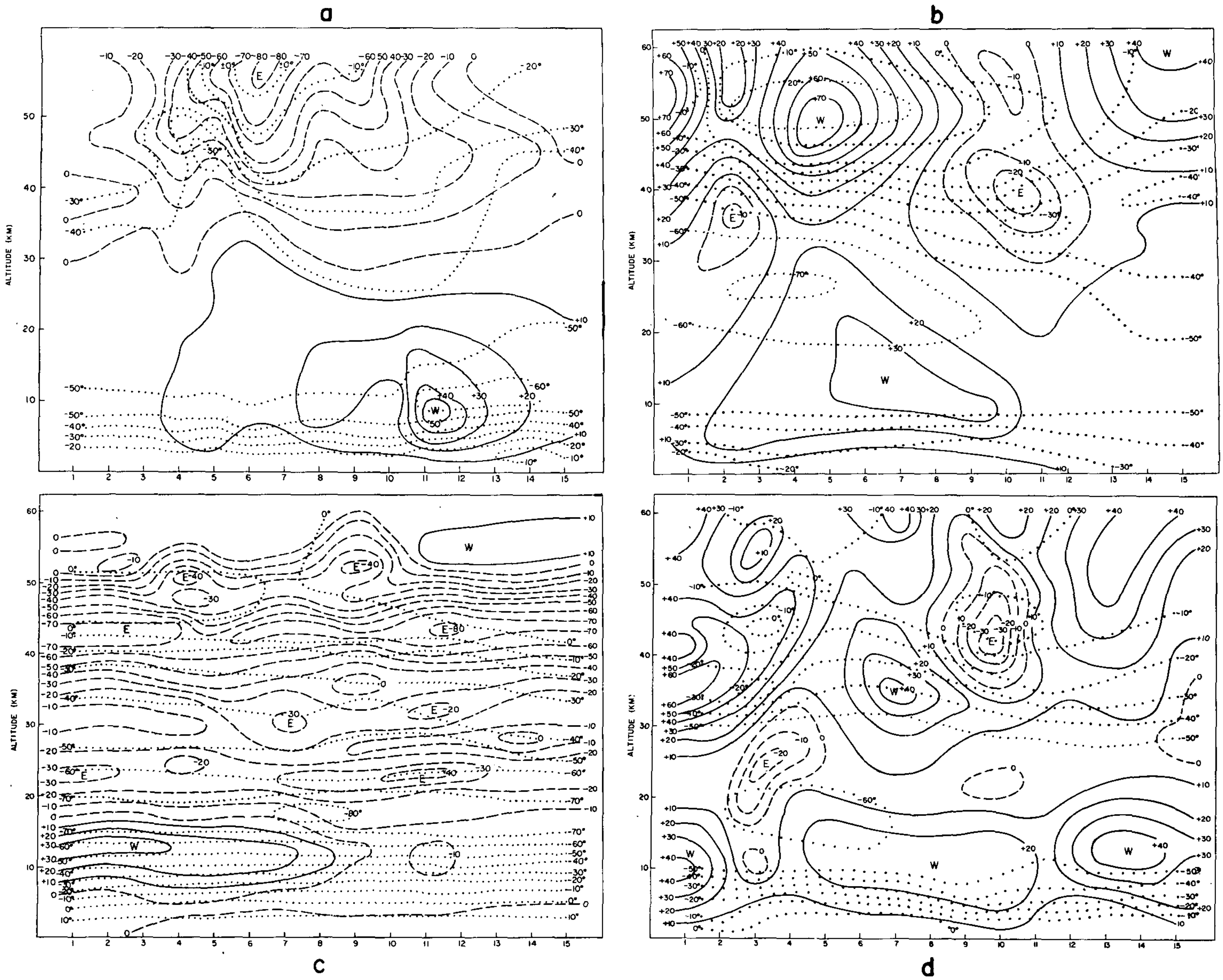

FIGURE 1.—Time section of zonal wind (m. sec.$^{-1}$) and temperature (°C.) Feb. 1–15, 1966, for a) Fort Greely, Alaska, b) Fort Churchill, Canada, c) Ascension Island, and d) White Sands Missile Range, N. Mex.

error in temperature (T), there was an error of 67.44 gp.m. in layer thickness and therefore a corresponding error in the 1-mb. surface height. 2) The error in calculating the 10-mb. height (z) will be additive to the error in the 1-mb. z. 3) The 1-mb. z was calculated from the temperature at approximately solar noon, and the 10-mb. z at 1200 GMT; consequently, the time lag for z at 1 mb. with respect to z at 10 mb. was equal to the time in hours which is a function of longitude west of the station. Diurnal and semidiurnal changes (Beyers and Miers [5]) in the 10-mb. z should be added to the calculated 1-mb. z to obtain a more realistic value of the 1-mb. z at time of observation. Since all stations had not performed diurnal temperature studies, this portion of height error analysis was omitted.

2. DISCUSSION

The normal winter circulation from 30 to 50 km. is characterized by strong westerlies in polar regions and a weak flow over the subtropics. The description of the wind and temperature patterns that follow refers to anomalies in these patterns which have been observed only during the winter months.

TIME-HEIGHT SECTIONS OF WIND AND TEMPERATURE

Sections of zonal and meridional wind and temperature from the surface to 60 km. during Feb. 1–15, 1966, were constructed for White Sands Missile Range, Fort Greely, Alaska, Fort Churchill, and Ascension Island and are illustrated in figures 1 and 2. The sections over Fort

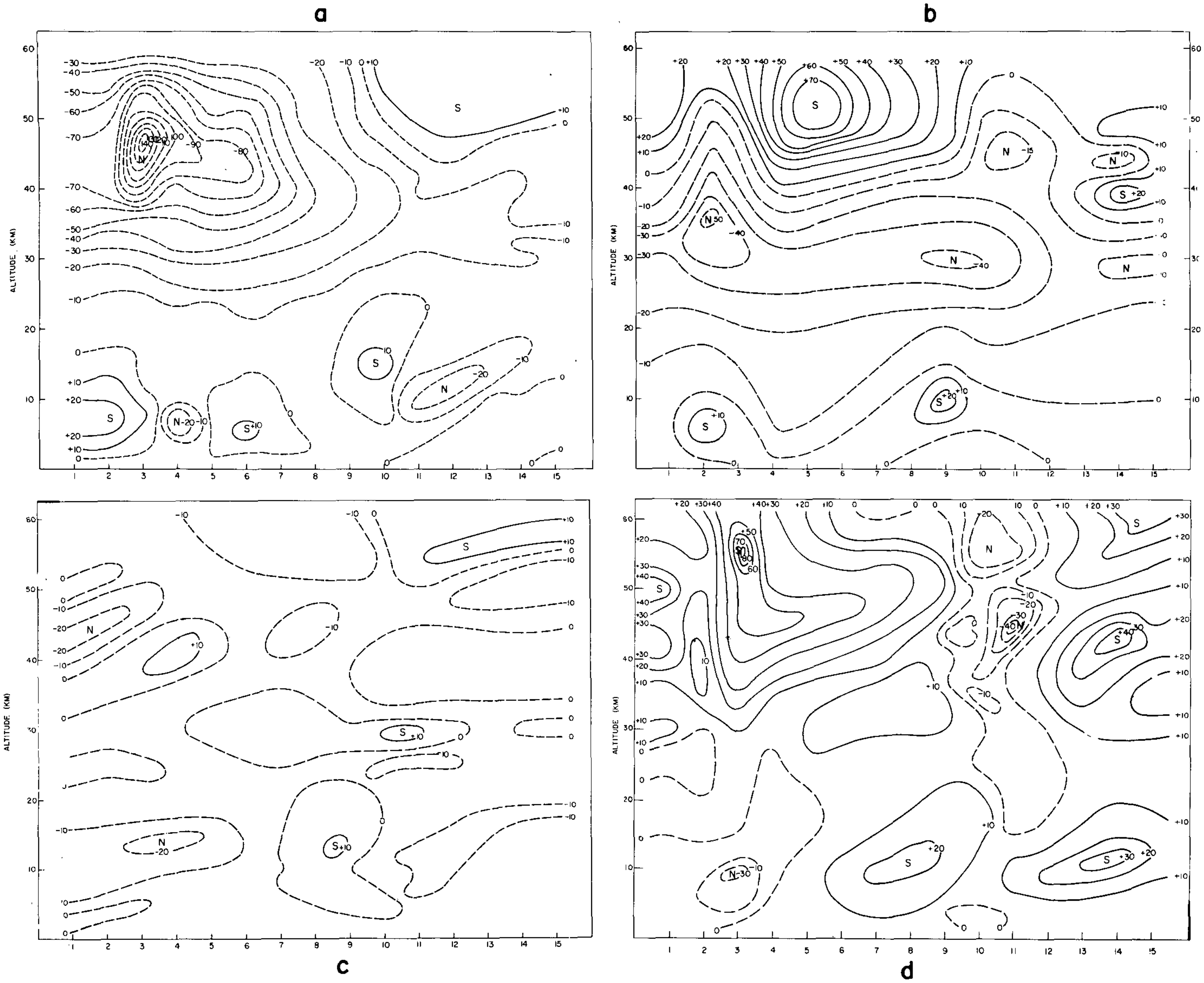

FIGURE 2.—Time section of meridional wind (m. sec.$^{-1}$) Feb. 1–15, 1966, for a) Fort Greely, Alaska, b) Fort Churchill, Canada, c) Ascension Island, and d) White Sands Missile Range, N. Mex.

Greely (fig. 1a and b) illustrate the duration and intensity of the anomalous circulation in the upper stratosphere and lower mesosphere over northern latitudes and also the apparent independent structure of the wind regime in the troposphere during this period. North winds were centered at 46 km. with maximum speeds above 140 m./sec. on Feb. 3, 1966, and east winds of 80 m./sec. were observed at 55 km. on Feb. 6, 1966. Cooling which took place during Feb. 3–5, 1966 (fig. 1a), at 44–47 km. attended the large change in the meridional circulation pattern.

A study of the 1-mb. maps demonstrated that these strong winds were located between a deep cyclone centered between Fort Churchill and Fort Greely, and a large anticyclone over eastern Siberia. The cold air was transported southwestward over the Pacific Ocean and the 1-mb. Low also moved in the same direction. Rapid warming occurred on Feb. 6 and 7, 1966, in these strata and the stratosphere remained warm until Feb. 11, 1966, as the northeast winds continued to decrease. The notable feature shown on the Fort Churchill zonal time section (fig. 1b) was the appearance of abnormally high temperatures between Feb. 2 and 10, 1966, above 45 km. A warm layer with temperatures above 20° at 50 km. represented a departure of 30°–40° above that usually observed. This warming propagated downward with time, e.g., the −40° isotherm lowered from 41 km. on Feb. 1, 1966, to 27 km. on Feb. 14, 1966. Moreover, the −30° temperature at 35 km. during the wind reversal on Feb. 10–11, 1966, was 30° higher than on Feb. 1, 1966. The northeast winds persisted above 30 km. for February 8 to 12 with greatest

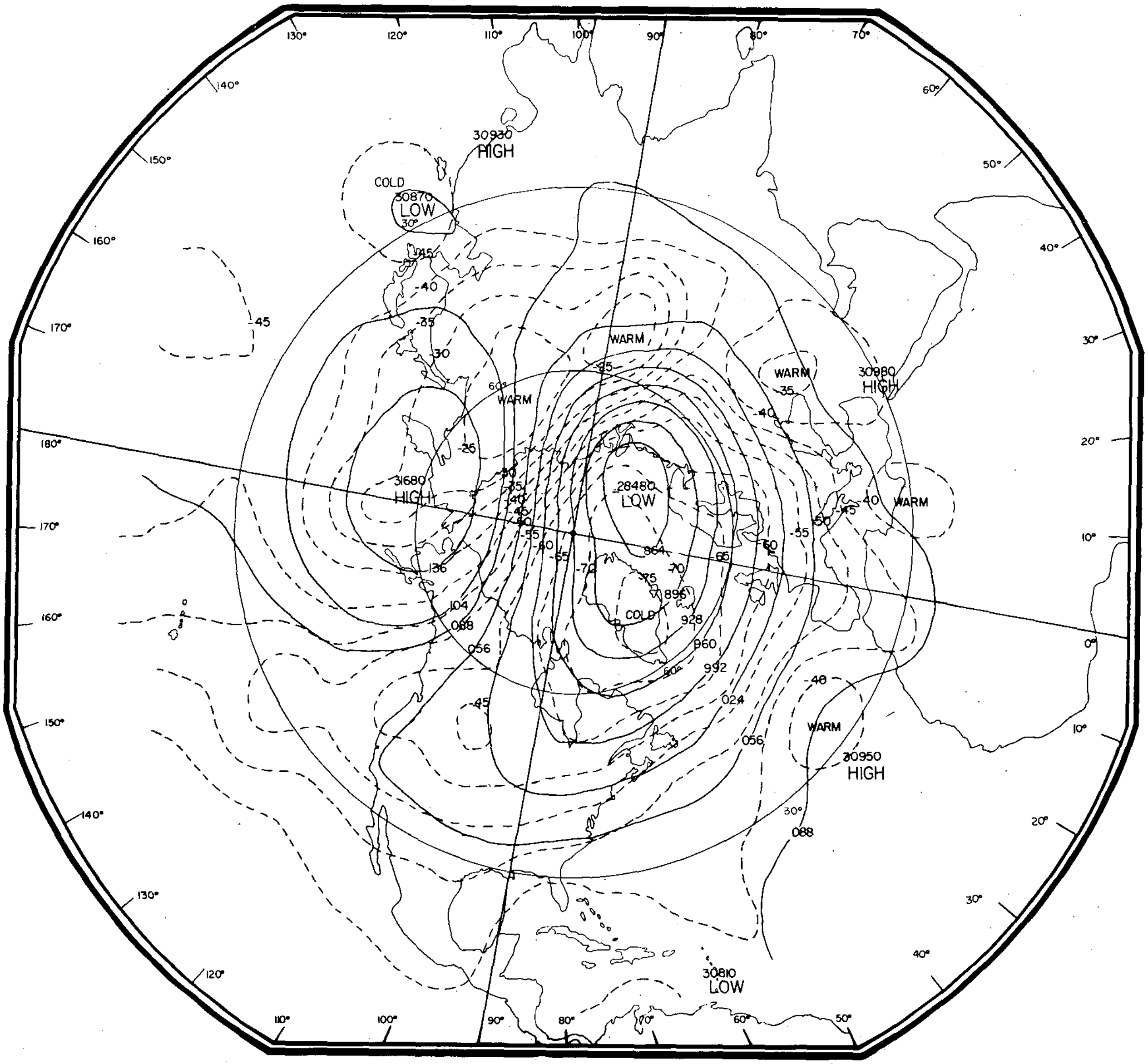

FIGURE 3.—10-mb. chart for 1200 GMT, Feb. 1, 1966; contours are solid lines at intervals of 320 gp.m. Isotherms are dashed lines at intervals of 5°C.

speeds at the 40–km. level. North winds dominated the circulation over Fort Churchill (fig. 2b) throughout the stratosphere below 40 km. South winds were observed above 40 km. from Feb. 3–9, 1966. Strongest southerlies which appeared in conjunction with warm air measured 66 m./sec. The duration and intensity of these southerly winds indicated to some extent the influence of the lower mesospheric cyclone which was located in western Canada. It was also evident that the base of the southerlies (40 km.) marked the lowest extent of this major circulatory system.

The zonal winds and temperatures over Ascension Island were of special interest for several reasons, namely, 1) Ascension Island (fig. 1c) was the only routine rocket observation station in the Southern Hemisphere near the Equator, where in this study the lowest temperatures were observed in the stratosphere; e.g., the −80° isotherm centered at 18 km. was the lowest temperature reported at any station; 2) the circulation was dominated by the summer anticyclone centered over the South Pole. The influence of the Southern Hemispheric polar anticyclone was illustrated by the large vertical extent of the easterlies which encompassed the entire stratospheric circulation. (Note the uniform structure of the easterlies with height as opposed to the highly variable behavior of the zonal wind regime at the northern latitude stations.) Easterly jets of 40 and 80 m./sec. were at 23 and 43 km., respectively, on Feb. 11, 1966. It is perhaps significant that the upper jets also existed over the low and midlatitude stations of the Northern Hemisphere a day or 2 earlier at the same altitudes. The weak structure of the meridional

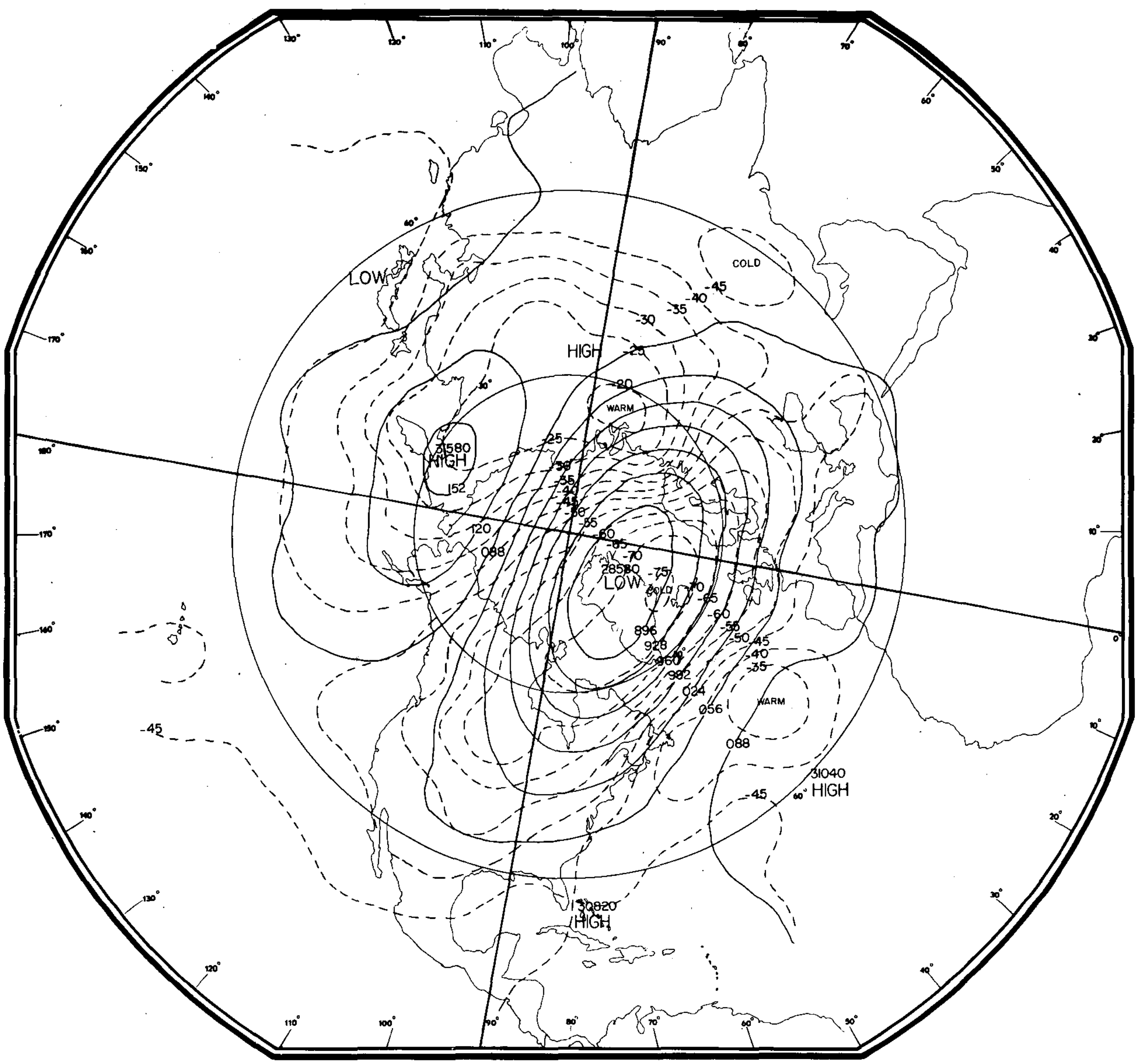

FIGURE 4.—10-mb. chart for 1200 GMT, Feb. 4, 1966; contours are solid lines at intervals of 320 gp.m. Isotherms are dashed lines at intervals of 5°C.

winds over Ascension Island (fig. 2c) indicated the lack of important synoptic eddy activity in the stratospheric summer Tropics.

The salient feature of zonal winds and temperatures at White Sands Missile Range (fig. 1d) was the wind reversal from a westerly to easterly direction (Feb. 8 through 11, 1966) extending vertically from 35 to 55 km. and centered at 43 km. A short period of easterlies appeared in the lower stratosphere between Feb. 2 and 4, 1966; however, a direct relationship connecting the two easterly regimes was not apparent. Westerlies dominating the circulation from the surface to the lower mesosphere during the beginning and end of the period is considered a normal winter profile. The isothermal pattern illustrated a slight warming (10–15°C.) a few days prior to and during the wind reversal. Over North America the duration and vertical extent of the easterly wind circulation was related to north winds; otherwise, south winds were observed in the circulation during this period. Time height sections of wind and temperature at Point Mugu, Calif., and Cape Kennedy, Fla., were not included because of the similarity of their patterns to those at White Sands Missile Range.

SYNOPTIC ANALYSES AT 10 MB.

The winter circumpolar Low continued to dominate the circulation from the North Pole to approximately 25°N. lat. during late November and early December 1965; however in mid-December 1965 there was a noticeable displacement of the Aleutian-Kamchatka anticyclone at 10 mb. and above. By mid-January the Aleutian anti-

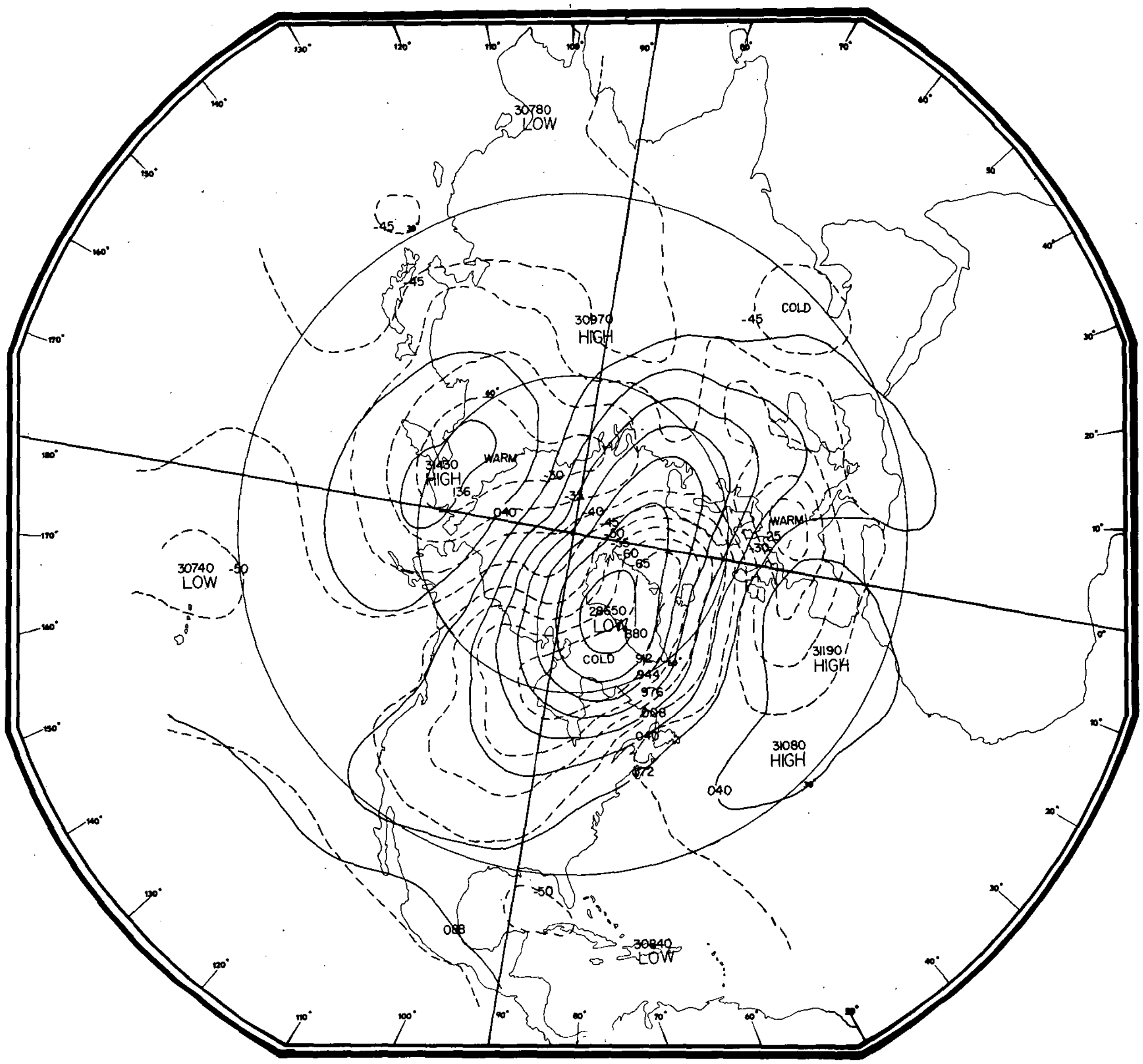

FIGURE 5.—10-mb. chart for 1200 GMT, Feb. 7, 1966; contours are solid lines at intervals of 320 gp.m. Isotherms are dashed lines at intervals of 5°C.

cyclone intensified and gradually displaced the polar Low toward the European sector of the hemisphere.

Figures 3 through 6 depict the fields of temperature and height at the 10-mb. surface over the Northern Hemisphere for Feb. 1, 4, 7, and 10, 1966, respectively.

The 10-mb. analysis on Feb. 1, 1966 (fig. 3), illustrated the bicellular structure of the midstratospheric circulation over the Northern Hemisphere. The cyclone, which covered a major portion of the Northern Hemisphere north of 30°N. lat., was centered over the Barents Sea with a central height of 28.5×10^3 gp.m. The major trough associated with this cyclone extended from the center southwestward across Greenland and Hudson Bay into central United States. Concurrently, the Aleutian anticyclone was centered over the Bering Sea, east of the Kamchatka Peninsula, with a central height of 31.7×10^3 gp.m., representing a height range of 3,200 m. across these systems. The thermal field showed the coldest air in the cyclonic trough over Greenland. The warmest air, depicted by the −25° isotherm, covered most of Siberia. The most meaningful feature on the map was the intense character of the thermal gradient revealed by the 50° range of temperature found over the Siberian side of the Arctic Ocean.

By Feb. 4, 1966 (fig. 4), the low center had moved over northern Greenland, indicating that movement accelerated westward toward the center of cold air during the previous 3 days. The intensity of the Low and movement of its accompanying trough showed no appreciable change. The High moved westward from the Bering Sea to eastern

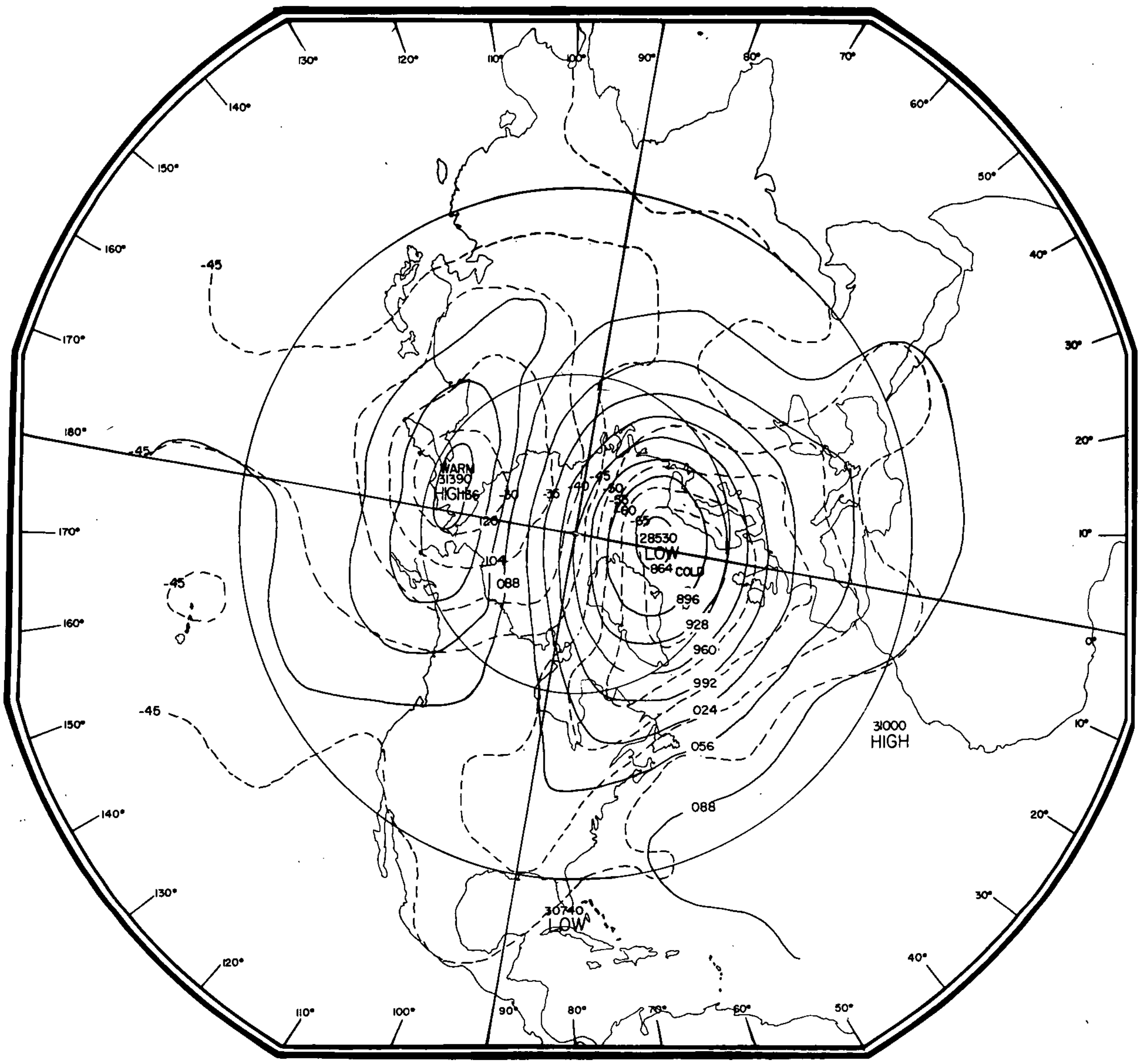

FIGURE 6.—10-mb. chart for 1200 GMT, Feb. 10, 1966; contours are solid lines at intervals of 320 gp.m. Isotherms are dashed lines at intervals of 5°C.

Siberia. The thermal gradient over the Siberian Arctic weakened slightly; however, the centers of cold and warm air remained almost stationary. The analysis on Feb. 7, 1966 (fig. 5), showed the low center over western Greenland continuing its movement to the west. Further relaxation of the thermal gradient over the Arctic Ocean was indicated as the temperature range decreased to 35°. The high pressure center remained over eastern Siberia, and further weakening was indicated by the central height falls of 150 m. The contour gradient was noticeably weakened, particularly over the United States. On Feb. 10, 1966 (fig. 6), the analysis illustrated the displacement eastward of the low pressure center and attendant circulatory system. The lack of contour gradient over the United States demonstrated the weakened wind circulation; however, a wind reversal was not apparent. Pressure systems contracted into northern latitudes during and following a wind reversal over midlatitudes.

SYNOPTIC ANALYSES AT 1 MB.

The geographical extent of the map was reduced to semihemispherical to accommodate the area (Western Hemisphere) required for analyses where rocketsonde data were available. In contrast to the topography of the height fields shown on the 10-mb. charts, where there was a single cyclone centered in the European Arctic, the field at the 1-mb. height had two cyclones, one located over North America and the other over northwestern Asia. Primary interest was in the synoptic changes connected with the North American cyclone and the Aleutian

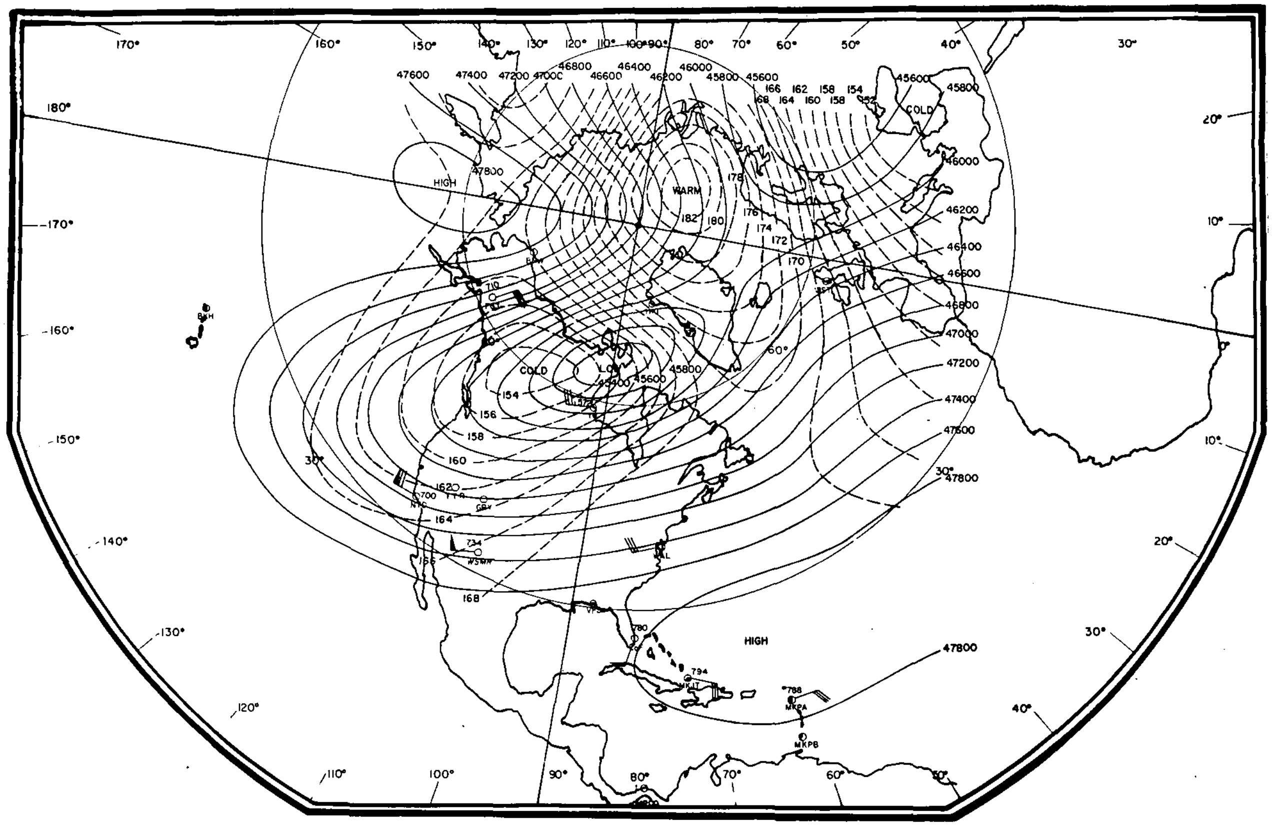

FIGURE 7.—1-mb. chart for local noon time, Feb. 1, 1966; contours are solid lines at intervals of 200 gp.m. Thickness patterns are dashed lines at intervals of 200 gp.m.

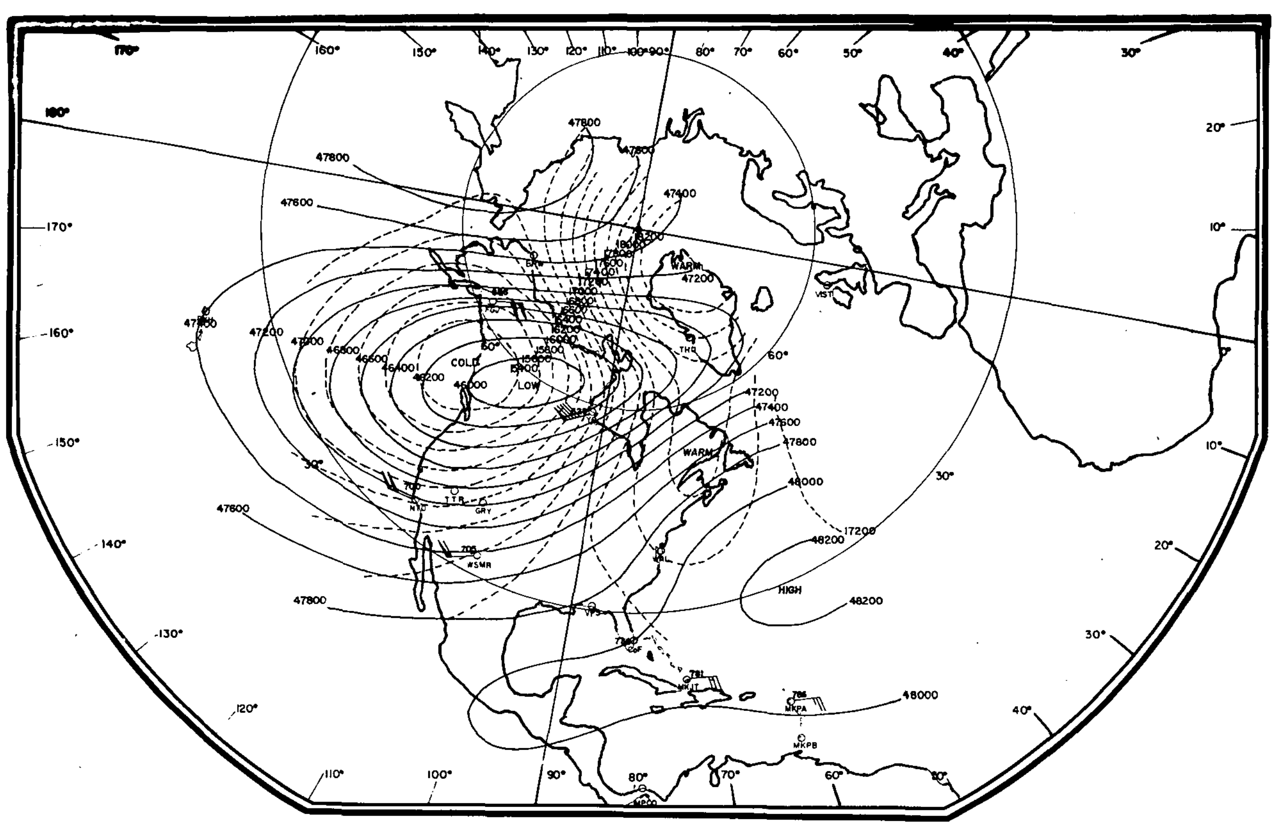

FIGURE 8.—1-mb. chart for local noon time, Feb. 4, 1966; contours are solid lines at intervals of 200 gp.m. Thickness patterns are dashed lines at intervals of 200 gp.m.

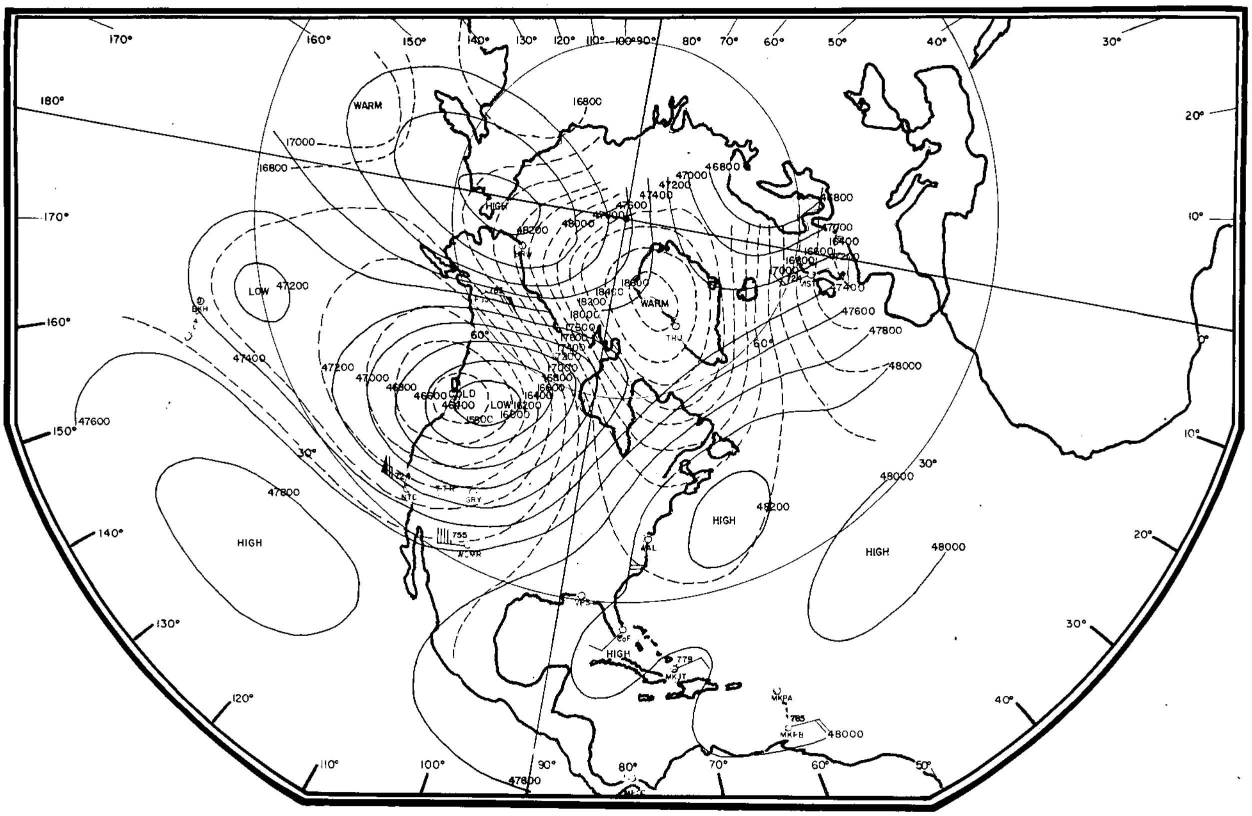

FIGURE 9.—1-mb. chart for local noon time, Feb. 7, 1966; contours are solid lines at intervals of 200 gp.m. Thickness patterns are dashed lines at intervals of 200 gp.m.

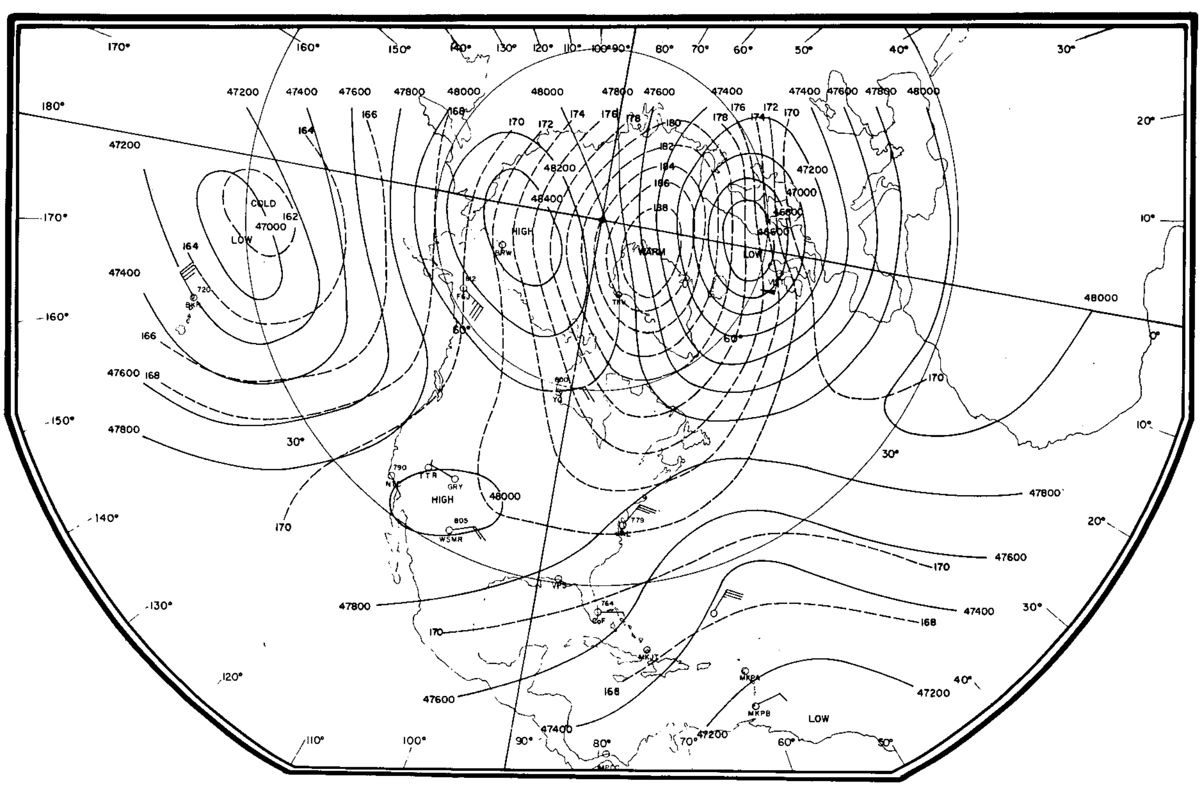

FIGURE 10.—1-mb. chart for local noon time, Feb. 10, 1966; contours are solid lines at intervals of 200 gp.m. Thickness patterns are dashed lines at intervals of 200 gp.m.

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anticyclone. Figures 7–10 portray the contour patterns of the 1-mb. surface on Feb. 1, 4, 7, and 10, 1966. The center of the cyclone on Feb. 1, 1966 (fig. 7), was over northcentral Canada with its height at 45.4 km. A trough extended from the center, southwestward across Vancouver Island and over the Pacific Ocean. The Aleutian High had a central height of 47.8×10^3 gp.m., which represented a range difference of 2.4×10^3 gp.m. from the Low to the east. The anticyclonic ridge was located over the International Date Line northward over the Pole, thence southward over the Atlantic Ocean. Strongest winds (50–70 m./sec.) were reported to the west and south of the low center; all other winds were less than 35 m./sec. The thickness analysis showed the coldest air over western Canada and the warm air centered over the European sector of the Arctic Ocean, with a warm tongue extending southward over Greenland and the north Atlantic Ocean (recall that the coldest air was found in this same area at the 10-mb. level).

By Feb. 4, 1966 (fig. 8), the 1-mb. Low had drifted southwestward over northern Saskatchewan with the central height increased by 600 gp.m. Fort Greely, Fort Churchill, Point Mugu, and White Sands Missile Range reported winds greater than 90 m./sec. which, incidentally, were the strongest winds shown on any of the synoptic maps during this period. The thickness analysis showed the coldest air over southwestern Canada and the warmest air over northern Greenland. A warm tongue penetrated southward along the east coast of Canada and the United States. The low pressure system continued to drift southwestward toward the center of cold air and on Feb. 7, 1966 (fig. 9), was centered over southwestern Canada while the Aleutian High moved northeastward toward the center of warm air. The tongue of warm air appeared to be spreading south and west covering much of eastern Canada and eastern United States. The influence of the westward moving Atlantic High was seen as the winds at Wallops Island backed to a southerly direction. Height values in the low center had increased 1×10^3 gp.m. since Feb. 1, 1966, indicating rapid filling of the system. The areal coverage of the low pressure system had substantially decreased.

The dissimilarity of the contour pattern on Feb. 10, 1966 (fig. 10), compared with the patterns on preceding maps was striking. The Aleutian High had continued to drift northeastward and was centered between Point Barrow, Alaska, and the North Pole with a central height of 48.4×10^3 gp.m. The Low had either moved rapidly westward over the Pacific Ocean or it had filled and remained as a shallow low center in the northwestern United States while the Low in the middle of the Pacific had deepened. The gradient of the contour pattern around the Low indicated continued weakening of the system as the central reading between February 1 and 10 increased 1.6×10^3 gp.m. The thickness pattern showed the warmest air persisting over northern Greenland, but the tongue of warm air had spread south and west covering much of Canada and the United States. This series of 1-mb. maps showed the easterlies of northern latitudes occupying successively lower latitudes, while the subtropical easterlies were displaced northward, merging in midlatitudes.

3. CONCLUSIONS

During past years, series of illustrations of synoptic stratospheric circulation change made by constant pressure analyses over time periods of less than 1 week have been restricted to the 10-mb. surface. This report has shown that synoptic variations occur in the stratospheric circulation which can be identified and tracked through the use of observations provided by the Meteorological Rocket Network. Moreover, these synoptic analyses performed at the 1-mb. level at 3-day intervals have revealed circulation systems which can be significantly different from those at 10 mb., particularly during the winter storm period. Further, analyses at these levels provided evidence that the circulation intensifies with height with higher wind speeds to the base of the mesosphere. It was also apparent that the atmospheric layer between 35 and 55 km. belonged to the same regime; however, marked changes in the slope of these systems were obvious. This fact has been supported recently by a series of 5-mb. synoptic analyses for this period published by the Free University of Berlin [6].

ACKNOWLEDGEMENTS

The author is indebted to Professor Walter J. Saucier of the University of Oklahoma for many valuable discussions and advice in writing this paper.

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[*Received December 8, 1967; revised February 5, 1968*]